Roadmap Theme 4 – Environment & Society

Introduction

The electrification of the transport sector has evolved rapidly in the past few years, driven by urgency to tackle a large-scale transition from the use of liquid fossil fuels and to achieve significant climate change mitigation. Even as widespread application and adoption is now taking place in society, the electrification of the transport sector is continually evolving, with some subsectors being ahead of others, and some still in the early phases of introduction. The shift to electrification is driven not only by the need to mitigate climate change. It is also influenced by concerns about public health and local air quality, and by national priorities such as energy security and independence.

Scope and boundaries

The main objective of thematic area *Environment & Society*, theme 4, is to help steer the development of electromobility towards long term sustainability hand in hand with meeting societal needs for transport, now and in the future. The research aims to identify environmental and socio-technical barriers of electrification technologies and support measures to overcome, work around or avoid these barriers, to enable a rapid large-scale transition of the transportation sector. To find solutions where we can enable a substantial scale-up of electric vehicles and vessels, with the smallest environmental impacts and the most efficient resource use, will be important to enable the introduction of the new technology in a sustainable way.

The research activities covered by this theme are expected to partly overlap or intersect the technology content of the other thematic areas within SEC and will investigate it on a different system level. Theme 4 aims at analyzing the environmental and societal aspects of the different subsystems represented in the other themes and on an overall system level. Analysis on an overall system level of environmental, economic and social aspects avoids sub-optimizations and promotes overall efficiency. Figure 1 illustrates that the theme interacts with and connects to all other theme areas.

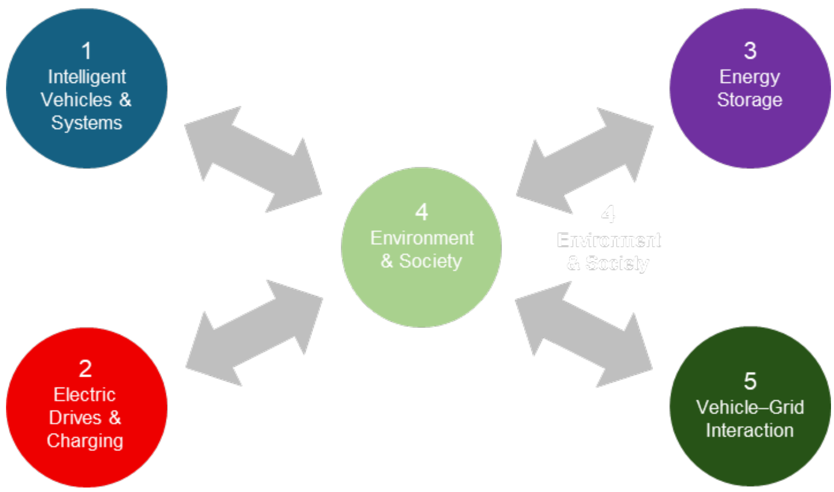

Figure 1. Theme 4 interaction and role in relation to the other themes.

Current trends and needs

The rapid implementation of electromobility in society involves a complex combination of new challenges with technical, behavioral, commercial, and governmental aspects, requiring that systems perspective is added to the state-of-the-art knowledge. Electrification, increasing levels of vehicle automation, logistics as a service as well as carpooling and shared mobility (ride sharing services) are prevalent trends that have emerged simultaneously in the transport sector the last few years. While technical advancements in the field are enabling these parallel transitions, they are also based on innovative business models and governed by policy directives. In addition, several powerful information technology tools are rapidly being developed. These include AI and sensor technologies for data-driven optimization, as well as also digital platforms for integrated mobility services, cybersecurity solutions and blockchains for upstream traceability and responsible sourcing of key raw materials. Such digitalization strengthens connectivity within the transport system, and across to energy networks and the built environment. Meanwhile, resilience – meaning robustness against disruptions and adaptability to changing conditions – becomes critical for these interconnected systems.

Environmental impact and resource use

The growing concerns regarding resource availability and environmental impact imply the need to design and adapt vehicles as well as the supporting infrastructure, for circular material flows and circular value chains, thereby reducing waste and increasing material efficiency. Equally important is to avoid unintentional shifting of environmental burden from one geographical site to another, or from one point in time to another, with no net benefits. For this reason, it is important to continuously monitor the effects of technical design changes and technology developments by assessing a broad spectrum of environmental impacts such that new problems can be addressed before they become major hurdles. Addressing these societal challenges will impact on the pace and efficiency of the transition, and on the acceptance of electromobility by society in general.

Battery electric vehicles are entering the market with increasingly larger battery size and longer range. This implies increased resource use for battery production, and possibly higher power levels will be requested for charging, shifting the requirements set on the charging equipment (in or outside the vehicle) as well as the grid to supply sufficient power and energy. Battery manufacturers and other automotive suppliers talk about upstream "vertical integration" and modularity to secure resource availability, enhance material efficiency, and reduce costs.

Second-hand EV-batteries are now beginning to enter stationary (for example battery parks for grid balancing) and semi-stationary (for example electricity backup on ships) applications. Improvements in the battery management systems lead to more uniform degradation and better predictions for the state of health of batteries on cell level, supporting the case for "second-life". There is also a discussion of business models based on leasing, which will incorporate future take-back of components for re-leasing to other applications, and eventually achieve effective steering of waste flows into material recycling to increase recycling rates. Another benefit of adopting business models based on leasing is that it helps minimize the financial risks associated with ownership and the long-term investment in EVs.

Larger and heavier batteries also influence the wear and tear of the roads and tires which causes increased particle emissions in aggregates of tire and road dust, with environmental risks posed by tire additives and road wear minerals. There is still limited knowledge about these emissions and particle properties such as size distribution and composition, which influence how particles spread in air and water, degrade in the environment, and impact both human health and ecosystems. In addition, much previous research mapping particles' impact on the human body has been based on combustion emissions, which differ in composition. Due to weight, EV tires also have designs which cause more noise.

Behavior and society

It is possible to identify several societal challenges that the development of electromobility will be facing in the coming years. Many are generic and similar for any emerging technology, for example lack of industry-wide standardization, unavailability of supporting regulations and infrastructure for charging, which is a key for societal adoption. In addition to these technical aspects, there is also the question of affordability and accessibility, ensuring technology and infrastructure equity, which refers to both the pricing of vehicles and that charging infrastructure installations do not exclude rural and low-income communities. For private cars, there is a need to know more about the users' behavior and their willingness to depart from the known flexibility and functionality provided by existing combustion-based propulsion to EVs, which offers high convenience when home-charging is possible, it demands other types of flexibility, for example charging stops during long-distance trips. This also relates to user-friendliness in charging, such as transparent pricing, so that occasional users or those without subscriptions can participate easily. For heavy-duty vehicles, there is a need to understand the impact of electromobility on transport efficiency and related systemic trade-offs, logistics planning, and charging. Addressing these knowledge gaps involves holistic analysis of electromobility, not just as technical challenges in the vehicles, or at the infrastructural level, but understanding all actors in the transport system, and assessing how the technology needs to evolve to match current and future expectations and needs.

Intelligent systems that advise the user on the most optimized charging options based on their driving preferences are under development. This could be further "gamified" by encouraging the user to alter driving behavior which would accrue "green points." Range anxiety has shifted to charging anxiety, especially for the heavy vehicles where queueing may pose a challenge for the freight industry where time is crucial. For personal transportation the discussions on access to electromobility and fair distribution of charging infrastructure regarding geographical areas, gender and income have increased. Where app-based car sharing services and carpools are growing in popularity in the larger urban areas, such services have not yet reached smaller cities and rural areas.

Business models

Shared mobility is another trend that continues to evolve. Beyond "mobility as a service," which integrates rental cars, taxis, and various forms of public transportation through digital platforms for booking and ticketing, the concept of "transport as a service" is gaining traction. This broader approach extends the idea to freight and logistics, enabling businesses and individuals to access flexible, on-demand transport solutions for goods and passengers alike. Together, these service-based models are reshaping how transportation is planned, delivered, and consumed.

Range anxiety and risk of delays due to queues at charging stations may push transport companies to demand solutions that minimize the risks e.g., battery swapping, e-roads and batteries on trailers. For transportation of goods, routes and transport flows are optimized together with specifically designed electrical vehicles and a dedicated charging infrastructure.

Higher investment cost in battery electric vehicles and lower operating cost for using them will challenge the present business models for both OEMs and transport operators. New business models based on Vehicle/Transport as a service will emerge. Research is needed on how this can enable new forms of co-operations in terms of data sharing and co-sharing of vehicles and joint fleet optimization.

The high focus on increasing energy efficiency and lowering manufacturing costs increases the integration of different powertrain components. Higher integration increases the challenges of cost- efficient disassembly, remanufacturing and eventually material recycling of all materials.

Technical trends

Different choices of materials and technology have different environmental impact, infrastructure requirements and resource use. Different solutions are tried out and developed, including fuel cells, lithium-ion batteries, sodium-ion batteries, battery swapping, structural batteries etc. The interest in fuel cells for heavy duty, shipping and aviation sectors also remains.

Data collection and processing in very large quantities using AI and sensor technologies, e.g., route optimization is often requested but may also be a challenge, especially when it comes to regulations such as the GDPR regulation. To be able to share data in a secure and trusted way data networks might be needed as well as the use of blockchains or other similar technologies to provide traceability upstream in the life cycles of components, linking responsible sourcing of key raw materials.

Policies and regulations

There are several new policies and regulations that have effect on various parts of the electromobility sector such as the vehicle, charging infrastructure, various types of fuels as wellas various transportation modes such as maritime shipping and aviation. It is not possible to mention all relevant policies and regulations in a roadmap, as new ones are always underway. Still, here are a few recently introduced or upcoming policies and regulations trends that affect the electromobility sector.

The Fit for 55 package is largely adopted, covering the EU Emissions Trading System (ETS) reform, including the Carbon Border Adjustment Mechanism (CBAM), as well as renewable energy and efficiency directives, and CO_2 standards for cars and vans. These measures underpin the EU's goal to cut emissions by 55% by 2030 and achieve climate neutrality by 2050.

The EU Battery Regulation (Regulation 2023/1542) is now in force It requires traceability, declared CO_2-footprints and a staged increase in recycled content for EV and industrial batteries. Key milestones include carbon footprint declarations starting in 2025, battery passports by 2027, and minimum recycled content thresholds from 2031 onward.

The EU still plans to ban sales of new cars and vans with combustion engines from 2035, though a review of the regulation is being fast-tracked amid industry pressure for flexibility and potential inclusion of e-fuels or highly efficient ICEs. Euro 7 regulation, adopted in 2024, introduces stricter limits for brake and tire particle emissions, durability requirements for batteries, and lifetime compliance rules. While exhaust limits for cars remain close to Euro 6, heavy-duty vehicles face tighter pollutant caps.CO_2 standards for heavy-duty vehicles have also been strengthened: a 15% reduction by 2025 remains, but targets rise to 45% by 2030, 65% by 2035, and 90% by 2040, with a 100% zero-emission requirement for new urban buses by 2035. These rules cover nearly all trucks, buses, and trailers.

The AI Act is being developed; the current proposal does not include vehicles but road traffic management systems. The EU is also preparing sector-specific rules for access to in-vehicle data, complementing the Data Act, to ensure cybersecurity and privacy while enabling innovation in connected services. Additionally, the Digital Omnibus proposal (2025) seeks to simplify GDPR and introduce new legal bases for sensitive data processing and harmonize data protection impact assessments.

Strategic research areas

This thematic area broadly covers four strategic areas for socio-economic-technical systems research within the field of electromobility:

1. Understanding technology diffusion and its impact on personal mobility and transport services
2. Securing resource availability, through efficient resource use and circularity
3. Assessment of environmental and societal impacts of transport technologies
4. Evaluation of policies and legislation to speed up sustainable electrification of transport

The *first* strategic area aims to investigate the interplay between technology and various actors in society. This includes understanding how and to what extent car users adopt their behavior to harvest personal and societal benefits of electromobility, as well as how and to what extent they are experiencing limitations that can hinder continued technology diffusion. What solutions are best for society, and how can the required shift in user behavior be supported? In the case of heavy vehicles, and for construction equipment, typical customers are transport operators or building firms. For these actors, the vehicle's total cost of ownership is in focus, and it is important to investigate how shifts in costs and the ability to provide specific transport services impacts the adoption of the new technology. Similar questions are also becoming increasingly relevant for cars, as new business models introduce mobility as a service for private users. It is furthermore important to improve the understanding of adoption of chargeable vehicles and the use and charging patterns of existing users of such cars. To ensure long-term success, research should also address how technology diffusion can build resilience in mobility systems and robust business models that withstand market fluctuations, infrastructure disruptions, and evolving user needs.

The *second* strategic area of the theme is aiming to research various strategies to secure the raw materials of electromobility with a long-term perspective by promoting circular material flows. It is directed at pre-empting future material availability issues that could arise from resource competition relating to key electromobility subsystems such as batteries and motors. This includes the integration of life cycle thinking into current product development and adding requirements on the design process to consider production, reuse in multiple applications, remanufacturing, and material recycling. It also encompasses research on other measures aiming for a circular economy, for example business models. Strategies must not only secure resources but also enhance system resilience against supply chain shocks and geopolitical risks. Robust circularity frameworks will help maintain material flows even under uncertain conditions.

The *third* strategic area of the theme is the monitoring of environmental impact, resource use, human health impacts and social issues of electromobility, with the aim of guiding ongoing development towards minimized burdens. A main societal driving force for electrifying vehicles is to decouple them from fossil fuel use and to enable reductions of greenhouse gas emissions. Inevitably, a rapid transition to electromobility may sometimes lead to undesired environmental side effects. Understanding such goal conflicts and addressing them strategically with proper action, e.g. by cost-efficient policies, is very important for reaching social readiness in each stage of technological implementation and diffusion. Beyond environmental monitoring, assessing the resilience of electromobility systems to climate-related risks, energy supply variability, and critical resource constraints is essential for sustainable implementation.

The *fourth* strategic area of the theme is studying measures, regulations and policy instruments that could be efficiently used to speed up electrification. It is equally important to understand the possible side-effects or goal conflicts between different policy proposals, or combined effects of multiple regulations, as well as understanding how long such incentives are being cost-effective. Policy evaluation should also include how regulations contribute to resilience and robustness in the transport ecosystem, ensuring that incentives and standards remain effective under changing economic, technological, and environmental conditions. Voluntary or mandatory standards for compliance or reporting are also addressed in this research area.

Outlook on global developments for electrification of transport

For the forecast section, theme 4 has selected to lift out a few areas of interest mentioned by the International Energy Agency IEA's Global EV Outlook, 2025.

Supply chain and market dynamics

Global EV sales have continued their rapid growth, reaching 17 million units in 2024 and projected to exceed 20 million in 2025, accounting for more than 25% of new car sales worldwide. China continues to be the world's EV manufacturing hub and is responsible for more than 70% of global production. While earlier supply chain disruptions were caused by the Covid-19 pandemic, the market has rebounded. This recovery is supported by falling battery costs, expanded model availability and robust policy measures in major markets such as China, Europe, and the United States.

Charging infrastructure

Charging infrastructure remains a critical challenge. Public charging points surpassed 5 million globally in 2024, yet deployment still lags the pace of EV adoption. The report notes that most charging will continue to occur at home or workplaces, but heavy-duty vehicle electrification requires dedicated fast-charging corridors, particularly in Europe and North America. To manage the growing complexity of integrating EVs with decentralized renewable energy sources, smart charging and digital grid technologies are highlighted as essential tools to turn grid integration challenges into opportunities.

Critical minerals and battery innovation

Battery supply chains and critical minerals are another focus area. Demand for lithium, nickel, and cobalt continues to rise, increasing pressure on global supply chains. High mineral prices and geopolitical risks have accelerated interest in alternative battery chemistries, such as sodium-ion batteries which are well-suited for cold climate applications. Novel technologies like solid-state lithium-ion batteries and lithium-sulfur batteries are specifically interesting for accelerating electrification in sectors that require higher energy densities, such as short-haul ferries and airplanes. Circularity strategies and second-life battery use are emphasized as key strategies to reduce reliance on mining and improve sustainability. Battery recycling is important, but its benefits will take time to materialize.